concrete pipe will usually best meet the above requirements, and is desirable when placed under the pavement of roadway and shoulders.

In the design of drainage systems in Delaware, it is recommended that concrete pipe be given prime consideration for all pipes, size 15" to 48" diameter, that are to be placed under roadway pavements. Pipes larger than 48" should be given special consideration as to type, end protection, velocity, bedding, soil condition, etc. Pipes placed under entrances, private drives, access roads with low traffic volumes or roads with dirt or surface-treated surfaces may be either concrete or corrugated metal, provided hydraulic and soil conditions can be met.

Strength Requirements

Pipes are manufactured to several different strength standards.

Reinforced concrete pipe comes in three classes. Class III is considered the standard strength and is used unless a stronger pipe is called for. Classes IV and V have thicker walls and more reinforcing steel and should be used where warranted for conditions of unusual loading or high fills.

The strength of corrugated steel and corrugated aluminum pipe is measured in terms of the gage (thickness of metal). Corrugated metal pipe also comes with three different sizes of corrugation -- 2-2/3" x 1/2," 3" x 1," and 5" x 1" -- where the first number is the distance between crests and the second is the depth of corrugations. The larger corrugation produces greater strength than the smaller -- with the same gage metal. At present, the 3" x 1" and 5" x 1" corrugations are used only for pipes of 36-inch diameter and larger.

The factor that primarily influences the strength requirements for pipes is the height of fill above the top of the pipe. Figures 6-29 and 6-30 identify the strength requirements for corrugated steel pipes and corrugated steel pipe arches. Maximum permissible cover is shown for various combinations of pipe diameter, pipe shape and thickness of metal. Maximum cover is based on the distance from the top of the pipe to the elevation of the finished road surface.

The figures also show minimum permissible cover for the various types and shapes of pipes. Minimum cover is measured from the top of the pipe to the top of the subgrade, since this will be the effective cover during construction operations.

Figures 6-31 and 6-32 show comparable strength requirements for corrugated aluminum pipe and corrugated aluminum pipe arches.

Strength requirements for concrete pipe culverts are shown in Figure 6-33 in terms of maximum permissible cover for each of the three classes of pipe. The minimum cover over concrete pipe is one foot.

Class III is the standard design for reinforced concrete pipes. When there is need to specify a stronger pipe, the pipe class must be clearly identified on the plans.

All depth-of-cover limitations are based on use of Type C bedding for culverts.

Culvert End Section Treatment

Usually some type of special treatment is warranted at the ends of culverts. Department Standard Sheets show details for end section treatments for both concrete and metal pipes.

Flared end sections or beveled ends should be considered for most pipe installations with a skew of 30 degrees or less. They provide for better entrance and exit flow characteristics -- and, since they fit closely to the roadway slope, they are less of an obstruction to a vehicle leaving the roadway surface.

Safety end structures (see Standard Sheets) should be provided at the ends of culverts through median crossovers. These end structures include metal grates on a relatively flat slope and serve as a safety feature for vehicles accidentally leaving the roadway and entering the median.

Special treatment often is needed at culvert ends as erosion control measures for protection of the embankment. Criteria for plain riprap and sack riprap are shown in the Standard Sheets.

Concrete headwalls at culvert ends are recognized as a potential traffic safety hazard, particularly when they are located close to the roadway shoulder. Generally, concrete headwalls should be avoided unless they are required for:

1. unique hydraulic conditions, or
2. structural support for very large metal culverts.

In the case of relatively high fills and steep side slopes, the terminal section of pipe may be left with a square end and no special end section treatment. The square end should extend about one foot beyond the intersection of the side slope with the natural ground. Normally, some type of erosion control protection should be considered for these installations.

Multiple Pipe Installations

Where two or more pipes are placed side by side, the spacing between adjacent pipes should be sufficient to permit effective compaction with hand tamps. Normally, a minimum separation of 3 feet is desirable. Closer spacing is permitted for unusual circumstances.

Skewed Installations

Wherever practicable, pipe culvert installations should be designed to conform as closely as possible to the natural drainage channels.

The degree of skew is measured as the angle between the pipe installation and a line perpendicular to the highway centerline. A culvert angle is described in terms of which end is forward -- left forward or right forward. For example, if the left end of the culvert is ahead of the line perpendicular

to the centerline, and the angle is 15 degrees, the installation would be described as "15^{o} skew left forward."

Culvert Length Measurement

For estimating purposes, culvert lengths are measured along the culvert flow line. To avoid the need for cutting sections, the design length should be in increments of two feet wherever practicable. When an installation requires that a section be cut (such as a storm sewer installation), payment will be for the actual length required.

Flared end sections are not considered a part of the culvert length. They are measured and paid for by the number of end sections installed.

Permanent Erosion Control

Most highway projects will require certain erosion control measures as a protection for roadside ditches and slopes. This section discusses those control measures of a permanent nature that are incorporated in project design. A following section will discuss temporary erosion control measures that must be considered by designers.

Delaware law prescribes certain policies and procedures with regard to erosion and sedimentation control. As a guide for implementing these requirements, the Delaware Department of Natural Resources and Environmental Control has published the "Erosion and Sediment Control Handbook." Reference should be made to this publication for more details on both permanent and temporary erosion control actions.

Vegetation

Barren soils are especially susceptible to erosion by wind and water. Established vegetation is the most natural and effective means of erosion protection on roadside slopes. It is the basic policy of the Department that

vegetation be restored to all areas disturbed during construction operations. Designers should consider the following requirements.

1. Topsoil. Prior to general grading operations, the contractor must remove existing topsoil from the areas to be disturbed. Such topsoil is stockpiled for future placement following completion of grading operations. If required, additional topsoil may be obtained from other sources. Quantity estimates must be prepared in terms of the square yards of area to be topsoiled.

2. Seeding. Seeding of all topsoil areas is prescribed in accordance with the criteria shown in the Standard Specifications. The quantity of seeding is estimated as the square yards of surface area actually covered.

3. Mulching. Mulch must be applied to all seeded areas to prevent water or wind erosion. Quantity estimates should be prepared in terms of square yards for:

   - mulching, straw or hay,
   - mulching, wood cellulose fibre,
   - mulching, woven paper, excelsior or jute.

   Additional quantity estimates must be made for securement of mulching, as follows.

   - mulch securement, chemical mulch binder (sq. yd.). (straw or hay mulch)
   - mulch securement, mulch crimper (sq. yd.). (straw or hay mulch)
   - asphalt mulch binder (gallons)

4. Sodding. Sodding should be called for at locations where it would be extremely difficult to effectively restore vegetation with normal seeding practices. Quantity estimates for sodding should be in terms of square yards.

Ditch Treatment

Ditch channels are particularly susceptible to erosion and often require some type of special erosion control measure. A principal factor in determining the type of treatment is the velocity of the water flow. General criteria for the various types of treatment are shown in Figure 6-34.

With relatively low velocities, well-established grass usually will provide adequate protection. This may be accomplished through normal seeding and/or sodding of the roadside. There may be need for some interim temporary erosion control measures (see following sections). With flat terrain and extremely low velocities (0.5 cfs or less), concrete lining may be considered to expedite the flow and dispersal of water.

With higher velocities it is necessary to consider a ditch lining of riprap or some other permanent protection. Details of these treatment are shown in the Department's Standard Sheets.

Fill Slope Protection

Where roadways and fill slopes are adjacent to a body of water and are subject to erosion, the slopes may be protected with stone riprap. This consists of toe trenches filled with a filter blanket of sand-gravel as a base for dumped stone riprap placed on the slope. (This procedure is not to be used where sinusoidal wave action erosion is encountered.)

On other high fills, consideration should be given to the construction of bituminous curbs and corrugated metal downspouts as shown in the Standard Sheets.

Other Erosion Control Devices

1. Interception Ditches -- Small ditches and berms immediately above the top of cut slopes for the purpose of intercepting surface runoff and carrying the water to a natural channel for disposal.

2. Culvert Riprap -- Stone or broken concrete riprap placed at the inlets and/or outlets of pipe culverts, possibly including a riprap apron at the outlet.

3. Energy Dissipators -- Several types of impact basins, drop structures or stilling wells at the outlets of culverts for the purpose of reducng or eliminating the effects of erosion. These are usually special-design items for unusually high velocities and local conditions particularly susceptible to erosion. Reference is made to Hydraulic Engineering Circular No. 14, "Hydraulic Design of Energy Dissipators for Culverts and Channels" (FHWA, December 1975).

Temporary Erosion and Sedimentation Control

Newly constructed side slopes and ditches are particularly susceptible to erosion. There is need to plan temporary control measures to be implemented during construction operations, to serve as protection until the permanent erosion controls are installed and the slopes are stabilized.

Also, the construction activities bring about conditions which may contribute to contamination of nearby natural bodies of water. Temporary measures often are needed during construction to prevent this from happening.

Where there are identifiable conditions that warrant these temporary controls, designers should make certain that the appropriate controls are clearly shown on the plan sheets, along with any additional right of way or easements that may be required. Details of the various erosion control items are shown in the Standard Sheets and are briefly described below.

Dikes

Several types of temporary dikes commonly are used to control storm runoff during construction. Usually they consist of a ridge of compacted soil,

and their use is limited to drainage areas of less than 5 acres. Typical installations include:

1. Diversion Dikes -- constructed immediately above a cut or fill slope to intercept storm runoff from higher areas and divert it away from exposed slopes to a stabilized outlet.

2. Interceptor Dikes -- constructed across disturbed right of way and similar sloping areas to shorten the length of exposed slopes, thereby reducing the potential for erosion.

3. Perimeter Dikes -- constructed at the perimeter of the site to divert runoff from the construction area.

4. Straw (or Hay) Bale Dikes -- installed across, or at the toe of a slope to intercept and detain small amounts of sediment from unprotected areas of less than 1/2 acre. They should not be on high sediment producing areas, above "high risk" areas, where water is concentrated in a channel, or where there is possibility of a washout.

Swales

Swales serve a purpose similar to dikes -- but they consist of an excavated drainage way rather than a ridge of compacted soil. Details for interceptor swales and perimeter swales are shown on the Standard Sheets.

Stone Outlet Structure

Stone outlet structures may be installed in conjunction with dikes at locations where they will provide a protected outlet for controlled overflow. Crushed stone is used instead of the compacted soil used in the remainder of the dike.

Level Spreader

This provides an outlet for concentrated runoff by dispersing the water on a zero percent grade at non-erosive velocities onto undisturbed area that is stabilized by existing vegetation. The design length of the spreader should be based on the estimated Q_{10}, as indicated on the Standard Sheet.

Sediment Traps

A sediment trap is a temporary basin of limited capacity formed by excavation and/or embankment. It is used to intercept sediment-laden storm runoff and to trap and retain the sediment in order to protect drainage ways, properties and rights of way below the trap. The drainage area for a sediment trap should not exceed 5 acres.

Sediment traps should be designed with dimensions to assure a volume (measured at the elevation of the crest of the outlet) of at least 1800 cubic feet per acre of drainage area. Embankments for sediment traps shall not exceed 5 feet in height as measured at the low point of the original groundline -- and shall have a minimum top width of 4 feet.

Each sediment trap shall be clearly shown on the plans, along with the following information:

1. type of trap,
2. size of outlet,
3. trap dimensions,
4. embankment height and depth of excavation, and
5. drainage area.

Storm Inlet Sediment Trap

This trap provides temporary protection against sedimentation entering storm inlets during construction operations. It consists of a basin sur-

rounding or adjacent to newly constructed storm inlets. Details are shown on the Standard Sheet.

Grade Stabilization Structures

These are temporary structures placed from the top to the bottom of a slope to convey surface runoff down the slope without causing erosion. The Standard Sheets show three optional designs, using rigid pipe slope drains, flexible pipe slope drains, or a paved chute or flume -- along with design criteria for sizes of pipe as related to drainage areas.